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ABSTRACT

This document consists of the three issues of this newsletter published in 1990. Designed to assist teachers at the secondary and college level in designing and presenting instruction on the topic of astronomy, typical articles in this newsletter include: (1) "Introductory Astronomy Glossary," which presents the definitions of 42 different terms; (2) "A Basic Astronomy Library," which lists over 100 books on various astronomy topics at different instructional levels; and (3) "The Latest News on the Hubble Space Telescope: Flawed but Working and Fixable." (CW)

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The Universe in the Classroom

A Newsletter on Teaching Astronomy

Sponsored by the:

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Special Issue
Combined Numbers 14 & 15

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Spring 1990

Editor's Note: In response to requests from a number of readers, we have put together two resource lists that educators at all levels can use in their teaching, lecturing, and study assignments: an ***Introductory Astronomy Glossary*** and an up-to-date ***Basic Astronomy Library.*** Like everything else that appears in this newsletter, we are happy to grant you unlimited permission to reproduce these resources for any noncommercial purpose. We welcome requests from our readers for other resource materials you would like to see us assemble.

— Andrew Fraknoi, *editor*

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Introductory Astronomy Glossary

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Asteroid: Any of the thousands of small rocky objects that orbit around the Sun, most of them between the orbits of Mars and Jupiter (although some pass closer to the Sun than Earth does and others have orbits that take them well beyond Jupiter.) The largest asteroid is one called Ceres; it's about as wide as the state of Texas.

Astronomical Unit: A unit of distance equal to the average spacing between the Earth and the Sun. Usually abbreviated "A.U.", it is equal to about 150 million kilometers (93 million miles), and is a distance that light takes about eight minutes to cover. It is a handy size to use for expressing distances in the Solar System. (For example, the diameter of the orbit of the most distant planet, Pluto, is about 80 A.U.)

Big Bang: The primeval explosion which most astronomers think gave rise to the Universe as we see it today, in which clusters of galaxies are moving apart from one another. By "running the film backward" — projecting the galaxies' motions backward in time — astronomers calculate that the Big Bang happened about 15 to 20 billion years ago.

Binary Star: A system of two stars, orbiting around one another. Binary (and triple and even higher multiples) stars are very common; astronomers estimate that about half of all stars are members of multiple-star systems. The nearest "star" to our solar system, Alpha Centauri, is actually our nearest example of a multiple star system — it consists of three stars — two very similar to our Sun and one dim, small, red star — orbiting around one another.

Black Hole: An object whose gravitational pull is so strong that — within a certain distance of it — nothing can escape, not even light. Black holes are thought to result from the collapse of certain very massive stars at the ends of their lives, but other kinds have been postulated as well: "mini black holes," for example, which might have been formed in turbulance shortly after the big bang. "Supermassive black holes" — with masses millions of times the Sun's — may exist in the cores of large galaxies.

Comet: A small chunk of ice, dust, and rocky material (only a few miles across) which, when it comes close enough to the Sun, can develop a tenuous "tail." Tails of comets are made of gas and dust that have been driven off the comet's surface by the Sun's energy and they always point away from the Sun (no matter what direction the comet is moving). Comets spend most of their time very far from the Sun, and are active only for a short period (a few months at most) as they move quickly around the Sun on their elongated orbits.

Constellation: A pattern of stars on the sky, named for a person, animal, or object (usually from mythology.) Astronomers use constellations to designate directions in

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space; for example the Great Galaxy "in Andromeda" lies in the direction from us marked by the pattern of stars we call Andromeda (the Princess of Ethiopia in Greek mythology). Just as patterns we see in the clouds are not permanent, neither are the star-patterns of constellations, since the stars move (albeit very slowly on the timescale of a human lifetime). The constellations of 100,000 years ago were quite different from today's. Astronomers now divide the sky into 88 sectors, each of which is named after the traditional constellation in that sector.

Cosmology: The branch of Astronomy that deals with the origin, large-scale properties, and the evolution of the observable universe.

Eclipse: The blocking of all or part of the light from one object by another. For example, a "Lunar Eclipse" occurs when the Earth's shadow falls on the Moon, preventing sunlight from illuminating all of its surface. A "Solar Eclipse" occurs when the Moon passes directly between us and the Sun, blocking part or all of its light from reaching us. Lunar eclipses can occur only when the Moon is on the opposite side of the Earth from the Sun (at Full Moon), while Solar Eclipses can happen only at New Moon. [See "Phases of the Moon."]

Equinox: Either of the two instants during the year when the Sun is directly over the EArth's equator. In the Spring, the Vernal Equinox occurs around March 21st, and in the Fall the Autumnal Equinox happens around September 21st (although the specific dates vary slightly from year to year.) At the time of the equinoxes, the length of day and night are very nearly equal all over the world. Spring and Fall officially begin at the instants of the Vernal and Autumnal Equinoxes, respectively.

Galaxy: A large assemblage of stars (and sometimes interstellar gas and dust), typically containing millions to hundreds of billions of member stars. A galaxy is held together by the gravitational attraction of all its member stars (and other material) on one another. Most galaxies are either of a flattened, spiral form or a fatter ellipsoidal shape without a spiral pattern. The "Milky Way Galaxy" of which our Sun is a part is a spiral galaxy with a disk about 100,000 light years across containing roughly 400 billion stars. Our Sun is in the disk, about 2/3 of the way out from the center, and orbits around the center for the Milky way taking about 200 million years to go around once.

Globular Cluster: A large congregation of stars (containing hundreds of thousands to about a million stars) which is spherical in form. About 150 globular clusters are members of our Milky Way galaxy, distributed in a round halo around the Galaxy's disk. Globular clusters, which can also be detected in other galaxies, are made up of very old stars (twice the age of the Sun or more).

Light Year: The distance light travels in one year in a vacuum. Light travels at a speed of about 300,000 kilometers per second (186,000 miles per second) in a vacuum. A light year is about nine and a half trillion kilometers (6 trillion miles) long.

Local Group: The relatively small cluster of galaxies of which our Milky Way is a part. It is known to contain about two dozen member galaxies, but most of those are "dwarf" galaxies, considerably smaller than our own. There are only two large galaxies in the local group: the Milky Way and the Andromeda Galaxy (about two million light years away from us in the direction of the sky marked by the constellation Andromeda.) The Local Group is about three million light years across, and is itself part of a "supercluster" of clusters of galaxies which is centered on a huge aggregate called "The Virgo Cluster."

Magnitude: A way of expressing the brightnesses of astronomical objects inherited from the Greeks. In the magnitude system, a *lower* number indicates a *brighter* object (for example, a 1st magnitude star is brighter than a 3rd magnitude star.) Each step in magnitude corresponds to a brightnesss difference of a factor of about 2.5. Stars of the 6th magnitude are the faintest the unaided human eye can see.

Magellanic Clouds: The two closest galaxies to us which are satellites of our own Milky Way. They are each irregular in form and relatively small (only about 1/5th as broad as the Milky Way's disk.) They are roughly a hundred thousand light years away from our Galaxy in a direction such that they can be seen easily only from Earth's southern hemisphere.

The Universe in the Classroom

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This newsletter is available without charge to teachers, school librarians and administrators, and youth group leaders, who request it on institutional stationery. Address all correspondence to:

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The first Europeans to record their existence were Ferdinand Magellan's crew in the early 1500's; to them, the two galaxies looked like small clouds separated from the Milky Way.

Meteor: A bit of solid debris from space, burning up in Earth's atmosphere due to friction with the air. (The luminous streaks they trace across the sky are commonly called "shooting stars," although they have nothing to do with stars!) Before entering Earth's atmosphere (with a typical speed of about 25,000 mph) the body is called a "meteoroid." If any of the object survives its fiery passage down through the air, then those parts which hit the ground are called "meteorites."

Milky Way: A faint band of hazy light that can be seen from clear, dark locations and which stretches all the way around the sky. When looked at using binoculars or a small telescope, it is seen to be composed of vast numbers of individual, faint stars. It is actually the disk of our own Galaxy — seen from our perspective (within the disk), the flat lens-shape of the Galaxy appears to surround us. Astronomers often use the term "Milky Way" to refer to our entire Galaxy, rather than to just its appearance in our sky. [See "Galaxy."]

Nebula: A cloud of gas and/or dust in interstellar space. (The word "nebula" in Latin means "cloud"; its plural is "nebulae.") Nebulae can make themselves apparent by glowing (as "emission nebulae"), by scattering light from stars within them (as "reflection nebulae"), or by blocking light from things behind them (as "obscuration nebulae").

Neutron Star: A crushed remnant left over when a very massive star explodes. Made almost entirely of neutrons (subatomic particles with no electric charge), these stellar corpses pack about twice as much mass as there is in the Sun into a sphere only about ten kilometers across. A teaspoonful of their material would weigh more than all the automobiles in the US put together. Some neutron stars are known to spin very rapidly, at least at the beginning, and can be detected as "pulsars"; rapidly flashing sources of radio radiation or visible light. The pulses are produced by the spinning of the neutron star, much like a spinning lighthouse beacon appears to flash on and off.

Nova: A star that abruptly and temporarily increases its brightness by a factor of hundreds of thousands. Unlike supernovae (much more violent explosions which destroy the stars that produce them), stars that "go nova" can do so more than once. Novae are thought to occur in binary stars in which one member is a compressed dwarf star (such as a white dwarf or a neutron star) orbiting close to a much larger star. According to this theory, material from the larger star's outer layers accumulates on the dwarf's surface, becoming ever hotter and more compressed by the dwarf's strong gravity, until the "stolen" material explodes. [See "supernovae," "binary star," "white dwarf," and "neutron star."]

Parsec: A unit of distance equal to about 3.26 light years (or, more precisely, equal to 206,265 Astronomical Units). Technically, a parsec is defined to be the distance from which the Earth and Sun would appear to be separated from one another by one second of arc (about the size a dime would appear to be if seen from a distance of two miles.)

Phases of the Moon: The changing appearance of the Moon as it orbits around the Earth. At "New Moon," the Moon is on the same side of the Earth as the Sun is, and we see only the part of the Moon which is in shadow (another term for New Moon is the "dark of the Moon"). A quarter of an orbit later (about a week after New Moon), we see the Moon illuminated by sunlight from the side. Thus one-half of the disk of the Moon which faces us is in sunlight — the right side as seen from Earth's northern hemisphere: this phase is called "First Quarter." About two weeks after New Moon, our satellite has traveled around to the other side of its orbit, and the side facing us also faces the Sun and is fully illuminated as we see it; that phase is called "Full Moon." Three-quarters of a lunar orbit after New Moon, at "Last Quarter," the Moon is again illuminated from the side (the left side as seen from the northern hemisphere). About a week after that, the Moon is New again, and the cycle starts over. Between First Quarter and Last Quarter, when more than half of the side of the Moon facing us in sunlight, the Moon is said to be "Gibbous." From Last Quarter to First Quarter, when more than half of the side of the Moon facing us is in shadow, the Moon is said to be a "Crescent."

Planet: A major object which orbits around a star. In our solar system, there are nine such objects which are traditionally called "planets": Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto. (There are no "official" specifications for how big an object must be to be called a planet rather than, for example, an "asteroid.") While no individual planet has ever been seen orbiting around another star, we wouldn't expect to see them, given the limits of current technology. It is suspected, though, that planets are common companions of stars.

Planetarium: A domed theater in which a special device in the center of the room projects a simulation of the nighttime sky onto a dome above the audience. Planetaria generally can show how the nighttime sky looks from anywhere on the Earth's surface at any time (for thousands of years into the past and future).

Quasar: One of a class of very distant (typically billions of light years away), extremely bright, and very small objects. The term "quasar" means "quasi-star" — that is, something that looks like a star but can't actually *be* a star. A typical quasar produces more light each second than an entire galaxy of stars does, and it does so from a region of space which is perhaps as small as our Solar System. Precisely how they produce their prodigious amounts of energy is not known, but astronomers suspect that their brilliance may be connected with the violent effects of very massive black holes at the centers of distant, dim galaxies on material right around them. [See "Black Hole."]

Radio Astronomy: The study of radio waves from objects in the universe. Radio and visible-light waves are the only kind of light-like radiation which can reach the ground easily

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from space. Partly because of this, radio astronomy became the first non-visible branch of astronomy, with large radio telescopes (instruments which can gather and focus radio waves from space) being first developed in the 1950's.

Red Giant: A very large, distended, and relatively cool star which is in the final stages of its life. A typical red giant, if placed where the Sun is in our solar system, might extend past the orbit of Mars. The relatively cool temperature of its outer layers (perhaps only 2,000 degrees Centigrade as compared to the Sun's 6,000 degrees) would make it look orange or red instead of yellowish-white. (The Sun is predicted to become a Red Giant about five billion years from now.)

Red Shift: The lengthening (or "stretching") of light waves coming from a source moving away from us. (If a source of light is moving toward us, the opposite effect — called a "Blue Shift" — takes place.) Light from all galaxies outside the Local Group is "red-shifted," indicating that they are moving away from us (and from each other). This phenomenon is called the "expansion of the Universe."

Second of Arc: A very small angle which is equal to 1/60th of a minute arc (which, in turn, is 1/60th of a degree). A line on the sky from horizon to horizon extends 180 degrees. A U.S. 10-cent piece seen from a distance of two miles has an apparent diameter of about a second of arc.

Satellite: An object orbiting around another, larger one. For example, smaller bodies orbiting around planets are called those planets' "satellites" (or, occasionally, "Moons" — but some astronomers frown on this use of the word "Moon" since they feel it should be reserved for Earth's natural satellite exclusively.) Probes we launch into orbit around the Earth are called "artificial satellites."

Solar System: The Sun and all things orbiting around it, including the nine major planets, their satellites, and all the asteroids and comets.

Solstice: Either of the two instants during the year when the Sun as seen from Earth is farthest north or south of the equator. The Summer Solstice (when the Sun is over the Tropic of Cancer) occurs around June 21st, the Winter Solstice (when the Sun is over the Tropic of Capricorn) happens around December 21st. In the Northern Hemisphere, summer and winter officially begin at the instants of the Summer and Winter Solstices, respectively.

Spectrum: The band of colors, from violet through red, obtained by passing white light through a prism (or another device that spreads light out into its component colors). Astronomical "spectroscopy," the study of the spectra of astronomical objects, is a very powerful tool in determining many characteristics of stars, nebulae, etc., since details of their spectra can reveal the materials they're made of and many of the physical conditions (temperature, pressure, and so on) within them.

Star: A large hot ball of gas which generates energy in its core by nuclear reactions. (The Sun is our local example of a star.)

Star Cluster: A group of stars which are held together by their mutual gravitational attraction. In the Milky Way, there are two different kinds of star of star clusters: ones called "open" (or "galactic") star clusters which are generally sparsely populated and exist only in the disk of the Galaxy, and the larger, older "Globular" clusters. [See "Globular Clusters."]

Sun: The star at the center of our solar system.

Supernova: An explosion which marks the end of a very massive star's life. When it occurs, the exploding star can outshine all of the other stars in the galaxy in total for several days and may leave behind only a crushed core (perhaps a neutron star or black hole). Astronomers estimate that a supernova explosion takes place about once a century in a galaxy like our Milky Way. While most supernovae in our Galaxy are probably hidden from our view by interstellar gas and dust, astronomers can detect supernova explosions in other galaxies relatively frequently.

Telescope: An instrument designed to gather light (or other kinds of radiation) from a large area and bring it to a focus, where the radiation can be analyzed. The primary purpose of most astronomical telescopes is to provide the brightest possible images, since most things that astronomers study are very faint. Thus, the "size" associated with a telescope (such as the "200-inch" on Palomar Mountain) refers to the diameter of its light-gathering area.

Universe: In astronomy, the sum total of all things which can be directly observed or whose physical effects on other things can be detected.

Variable Star: A star that changes its brightness. There are several classes of variable stars, including "periodic" variables (which change their brightnesses on a regular schedule, ranging from hours to many years) and "irregular" variables (which abide by no fixed schedule). Careful, long-term monitoring of variable stars is one major way in which amateur astronomers have made important contributions to research astronomy.

White Dwarf: The collapsed remnant of a relatively low-mass star (roughly one and a half times the Sun's mass and less), which has exhausted the fuel for its nuclear reactions and shines only by radiating away its stored-up heat. A typical white dwarf might have as much mass as the Sun, but have a size equivalent to the Earth's. Its density is roughly equivalent to that of a soda can into which a 747 airliner has been squeezed. (The Sun is expected to become a white dwarf at the end of its life.) ■

A Basic Astronomy Library

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Books on Astronomy in General

Bartusiak, M. *Thursday's Universe.* 1986, Times Books. Frontier areas of astronomy, as explained by a skilled science journalist.

Chaisson, E. *Cosmic Dawn.* 1981, Berkley paperback. An eloquent primer on the evolution of the universe and our place in it. (A sequel, called *The Life Era,* was published by Atlantic Monthly Books in 1987.)

Ferris, T. *Galaxies.* 1980, Stewart, Tabori & Chang. Lavishly illustrated introduction to the large-scale cosmos by a noted science writer.

Goldsmith, D. *The Astronomers.* 1990, St. Martin's Press. Focuses on the work of two dozen key astronomers. (Ready in late 1990.)

Hartmann, W. & Miller, R. *Cycles of Fire.* 1987, Workman. Over-sized paperback with gorgeous color illustrations, introducing the realms of the stars and galaxies.

Jastrow, R. *Red Giants and White Dwarfs,* 2nd ed. 1979, Warner paperbound. Good, basic book on the evolution of the universe and humankind.

Preiss, B. & Fraknoi, A., eds. *The Universe.* 1987, Bantam. Collection of introductory articles by noted astronomers and science fiction stories inspired by good science.

Preston, R. *First Light.* 1987, Atlantic Monthly Books. Eloquent introduction to modern astronomy through the life and work of a few of its finest practioners.

Sagan, C. *Cosmos.* 1980, Ballantine paperback. A superbly-written, highly personal tour of the universe; based on the PBS TV series.

Trefil, J. *Space Time and Infinity.* 1985, Smithsonian Press. A beautiful coffee table book introducing modern astronomy.

Books about our Solar System as a Whole

Chapman, C. & Morrison, D. *Cosmic Catastrophes.* 1989, Plenum. Fascinating introduction to impacts, collisions, and solar system violence.

Eliott, J. & Kerr, R. *Rings.* 1984/7, MIT Press. Introduction to the rings around Jupiter, Saturn, and Uranus.

Frazier, K. *Solar System.* 1985, Time-Life. Profusely illustrated guide to the planets by a fine science writer.

Miller, R. & Hartmann, W. *The Grand Tour.* 1981, Workman paperbound. A guide to the solar system, illustrated with photos and paintings.

Morrison, D. & Owen, T. *The Planetary System.* 1988, Addison-Wesley. A fine up-to-date textbook that can be read for pleasure.

Preiss, B., ed. *The Planets.* 1985, Bantam. A collection of authoritative articles about each planet and some science fiction based on them.

Books About Specific Planets

Burgess, E. *Venus: An Errant Twin.* 1985, Columbia U. Press.

Cattermole, P. & Moore, P. *The Story of the Earth.* Cambridge U. Press.

Davis, J. *Flyby.* 1987, Atheneum. Mainly about Uranus, but with sections on Jupiter and Saturn.

Hockey, T. *The Book of the Moon.* 1986, Prentice Hall.

Littmann, M. *Planets Beyond: The Outer Solar System.* 1988, Wiley. Good introduction to Uranus, Neptune, and Pluto.

Moore, P. *The Planet Neptune.* 1988, Horwood/Wiley.

Morrison, D. & Sams, J. *Voyage to Jupiter.* 1980, NASA Special Publication #439, US Gov't Printing Off.

Morrison, D. *Voyages to Saturn.* 1982, NASA Special Publication #451, US Gov't Printing Off.

Strom, R. *Mercury: The Elusive Planet.* 1987, Smithsonian Inst. Press.

Washburn, M. *Mars at Last.* 1977, Putnam's.

Tombaugh, C. & Moore, P. *Out of the Darkness: The Planet Pluto.* 1980, Stackpole Books. (Out of print; but worth searching for.)

Books About Asteroids, Comets, and Meteorites

Chapman, R. & Brandt, J. *The Comet Book.* 1984, Jones & Bartlett paperbound. Introduction to comets by two noted experts in the field. Should soon be available in a revised edition from W. H. Freeman & Co.

Dodd, R. *Thunderstones and Shooting Stars: The Meaning of Meteorites.* 1986, Harvard U. Press.

Kowal, C. *Asteroids: Their Nature and Utilization.* 1988, Horwood/Wiley. Best introduction.

McSween, H. *Meteorites and their Parent Planets.* 1987, Cambridge U. Press. What meteorites are and where they come from.

Sagan, C. & Druyan, A. *Comet.* 1985, Random House. Beautiful book of comet science and lore, with good background on the solar system.

Whipple, F. *The Mystery of Comets.* 1985, Smithsonian Inst. Press. Personal account by the scientist who first explained the nature of comets.

Books about the Sun

Frazier, K. *Our Turbulent Sun.* 1983, Prentice-Hall. A science writer reviews the modern picture of our local star.

Friedman, H. *Sun and Earth.* 1986, Scientific American Library. Very nice primer on the Sun and its relationships with our own planet.

Noyes, R. *The Sun, Our Star.* 1982, Harvard U. Press. Good introduction to the astronomy of the Sun by a Harvard astronomer.

Wentzel, D. *The Restless Sun.* 1989, Smithsonian Institution Press. Excellent and up-to-date.

Books about Stars and Their Evolution

Cohen, M. *In Darkness Born: The Story of Star Formation.*

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1988, Cambridge U. Press. Introduction to stellar infancy and youth.
Greenstein, G. *Frozen Star.* 1983, Freundlich. Eloquent book about the death of stars and what it is like being an astronomer today.
Kaler, J. *The Stars and their Spectra.* 1989, Cambridge U. Press. Definitive book on what we can learn about stars by decoding their light. (Somewhat more advanced.)
Kaufmann, W. *Black Holes and Warped Spacetime.* 1979, Freeman paperbound. Best introduction to black holes and the theories behind them.
Kaufmann, W. *Stars and Nebulas.* 1979, Freeman paperbound. Brief primer on stars and their lives.
Kippenhahn, R. *100 Billion Suns: The Birth, Life, and Death of the Stars.* 1983, Basic Books. Nontechnical review of stellar evolution.
Marschall, L. *The Supernova Story.* 1988, Plenum. Excellent introduction to exploding stars and Supernova 1987A.
Moore, P. *Astronomers' Stars.* 1987, Norton. Profiles of individual stars whose understanding was crucial to the progress of astronomy.
Verschuur, G. *Interstellar Matters.* 1989, Springer-Verlag. A history of how we learned about the gas and dust between the stars.

Books about Galaxies and Quasars

Harrington, S., et al. *Learning About Quasars.* 1990, Astronomical Society of the Pacific information packet. Collection of articles about observations of quasars and theories about what they might be.
Hodge, P. *Galaxies.* 1986, Harvard U. Press. A thorough introduction to our modern understanding of galaxies.
Kaufmann, W. *Galaxies and Quasars.* 1979, Freeman paperbound. Clear basic guide to what lies beyond our Milky Way Galaxy.
Wright, A. & H. *At the Edge of the Universe.* 1989, Horwood/Wiley. Searching for the most distant objects, especially quasars.

Books about the Origin and Evolution of the Universe

Barrow, J & Silk, J. *The Left Hand of Creation: Origin and Evolution of the Expanding Universe.* 1983, Basic Books. A good up-to-date discussion of modern theories and observations.
Cornell, J., ed. *Bubbles, Voids, and Bumps in Time.* 1989, Cambridge U. Press. Excellent articles on mapping and understanding the universe.
Ferris, T. *The Red Limit,* 2nd ed. 1983, Morrow/Quill paperbound. Good history of how large-scale properties of the universe were discovered.
Gribbin, J. *In Search of the Big Bang.* 1986, Bantam paperbound. Thorough, readable introduction to our quest for the universe's origin.
Harrison, E. *Cosmology.* 1981, Cambridge U. Press. A superb, literate textbook on large-scale questions about the universe.
Pagels, H. *Perfect Symmetry.* 1985, Bantam. A readable introduction to the science of the universe beginning, from the perspective of a physicist.
Trefil, J. *The Moment of Creation.* 1983, Macmillan paperbound. Fine introduction to our modern understanding of the Big Bang. (See also his *The Dark Side of the Universe,* 1988, Scribner's.)
Tucker, W. & K. *The Dark Matter.* 1988, Morrow. On the quest for the "hidden mass" of galaxies and the universe.

Books about Invisible Astronomy

Field, G. & Chaisson, E. *The Invisible Universe.* 1985, Birkhauser. About the many interesting phenomena revealed by modern instruments but not visible to the eye, and about plans for future telescopes.
Friedlander, M. *Cosmic Rays: Tracking Particles from Space.* 1989, Harvard U. Press.
Tucker, W. & Giacconi, R. *The X-Ray Universe.* 1985, Harvard U. Press. Fine introduction to cosmic phenomena that produce X-rays.
Verschuur, G. *The Invisible Universe Revealed.* 1987, Springer-Verlag. A fine introduction to the discoveries and techniques of radio astronomy.

Books about the Search for Life Elsewhere

Goldsmith, D. & Owen, T. *The Search for Life in the Universe.* 1980, Benjamin/Cummings. A basic introductory text in this field.
McDonough, T. *The Search for Extraterrestrial Intelligence.* 1987, John Wiley. Good-humored, basic book.
Rood, R. and Trefil, J. *Are We Alone?* 1981, Scribners paperbound. Popular-level introduction to life out there and the search.

Books about Telescopes and Other Instruments

Cohen, M. *In Quest of Telescopes.* 1980, Cambridge U. Press. Nice book on what it is like to use big telescopes and be an astronomer today.
Cornell, J. & Gorenstein, P. *Astronomy from Space.* 1983, MIT Press. Chapters by various astronomers on the results from and plans for exploring the universe with instruments in space.
Davies, J. *Satellite Astronomy.* 1988, Horwood/Wiley.
Field, G. & Goldsmith, D. *Space Telescope: Eyes Above the Atmosphere.* 1990, Contemporary Books.
Krisciunas, K. *Astronomical Centers of the World.* 1988, Cambridge U. Press. History of major observatories from ancient days through today.
Tucker, W. & K. *The Cosmic Inquirers.* 1986, Harvard U. Press. Well-written stories of some of the biggest telescopes on Earth and in space.

Books on Computers and Astronomy

Burgess, E. *Celestial Basic.* 1982, Sybex.
Duffett-Smith, P. *Astronomy with Your Personal Computer,* 2nd ed. 1987, Cambridge U. Press.
Duffett-Smith, P. *Practical Astronomy with Your Calculator,* 3rd ed. 1988, Cambridge U. Press.
Genet, R. & Hayes, D. *Robotic Observatories.* 1989, AutoScope Corp., P.O. Box 40488, Mesa, AZ 85274.

Lawrence, J. *Basic Astronomy with a PC.* 1989, Willmann-Bell.

Books on the History of Astronomy

DeVorkin, D. *Race to the Stratosphere: Scientific Ballooning.* 1989, Smithsonian Inst. Press.

Evans, D. *Under Capricorn: A History of Southern Hemisphere Astronomy.* 1988, Adam Hilger. Astronomical developments in Australia & elsewhere.

Ferris, T. *Coming of Age in the Milky Way.* 1988, Morrow. Eloquent, poetic book on the development of our ideas about the universe.

Gingerich, O., ed. *Astrophysics and 20th Century Astronomy to 1950.* 1984, Cambridge U. Press. Excellent collection of articles; the first in a series of historical collections from Cambridge.

Krupp, E. *Echoes of the Ancient Skies.* 1983, NAL paperbound. Introduction to the astronomy of earlier civilizations around world.

Osterbrock, D., et al. *Eye on the Sky.* 1988, U. of California Press. The history of the Lick Observatory, the first of the major astronomical observing centers in the U.S.

Sheehan, W. *Planets and Perception.* 1988, U. of Arizona Press. History of progress and reversals in understanding the planets.

Introductory Manuals for Sky Observing

Berry, R. *Discover the Stars.* 1987, Harmony/Crown. A fine introduction by the editor of Astronomy magazine, with clear maps.

Beyer, S. *The Star Guide.* 1986, Little Brown paperbound. A guide to the 100 brightest stars for beginners; good charts.

Chartrand, M. *Skyguide.* 1982, Golden Press paperback. Good compact handbook for beginners, with good illustrations.

Cherrington, E. *Exploring the Moon Through Binoculars and Small Telescopes.* 1984, Dover paperbound. Good guide to a variety of lunar observations.

Harrington, S. *Selecting Your First Telescope.* 1983, Astronomical Society of the Pacific. Pamphlet on what telescope do, different types of instruments, and what to do with a new telescope.

Mayer, B. *Starwatch.* 1984, Putnam paperbound. An eccentric but clever guide on constructing star-finders from simple household materials.

Menzel, D. & Pasachoff, J. *A Field Guide to the Stars and Planets,* 2nd ed. 1983, Houghton-Mifflin paperback. Updated edition of a classic guide, full of information and with good new maps.

Moore, P. *Exploring the Night Sky with Binoculars.* 1986, Cambridge U. Press. A friendly introduction with clear instructions.

Muirden, J. *Astronomy with Binoculars.* 1984, Arco paperback. A pleasant and useful book for scanning the sky with binoculars.

Ridpath, I. & Tirion, W. *Universe Guide to Stars and Planets.* 1984, Universe paperback. Compact guide to sky with constellation maps.

Schaaf, F. *Wonders of the Sky.* 1983, Dover. An amateur astronomer's enthusiastic guide to the joys of naked-eye observing.

Whitney, C. *Whitney's Star Finder,* 4th ed. 1985, Knopf paperbound. Clear, basic primer on sky phenomena & constellations. (Updated regularly.)

Books for Serious Amateur Astronomers

Berry, R. *Build Your Own Telescope.* 1985, Scribners. A good step-by-step manual for making telescopes, by the editor of *Astronomy* magazine.

Jones, K. *Webb Society Deep Sky Observer's Handbook.* (5 volumes) 1982, Enslow. Background info and rich catalogs of objects to observe.

Levy, D. *Observing Variable Stars: A Guide for the Beginner.* 1989, Cambridge U. Press.

Newton, J. & Teece, P. *The Guide to Amateur Astronomy.* 1988, Cambridge U. Press. Thorough primer by two Canadian amateurs.

Sherrod, P. *A Complete Manual of Amateur Astronomy.* 1981, Prentice-Hall paperbound. Excellent guide to observing techniques and projects.

Texereau, J. *How to Make a Telescope,* 2nd ed. 1984, Willmann-Bell. A wealth of detailed information on making a telescope from scratch.

A Few Selected Books for Children

Apfel, N. *Astronomy Projects for Young Scientists.* 1984, Arco paperbound. Good, simple astronomy activities for junior high level and up.

Asimov, I. *Isaac Asimov's Library of the Universe.* 1988-90, Gareth Stevens. Beautifully produced, basic astronomy series for ages 8 - 12.

Berger, M. *Bright Stars, Red Giants, and White Dwarfs.* 1983, Putnam. Brief introduction to stars and their evolution. [Ages 10 -15]

Branley, F. *Saturn: A Spectacular Planet.* 1983, Crowell. Picture book summarizing our knowledge of the ringed planet. [Ages 7 - 11]

Branley, F. *Space Telescope.* 1985, Crowell. Illustrated introduction to telescopes and the big one to go in space. [Ages 8 -11]

Burnham, R. *The Star Book.* 1983, Astromedia/Cambridge U. Press. Book of cardboard star maps & instructions for beginners. [12 to adult]

Hatchett, C. *The Glow-in-the-Dark Sky Book.* 1988, Random House. [All ages.]

Krupp, E. & R. *The Big Dipper and You.* 1989, Morrow. A delightful illustrated book on stars and constellations. [Ages 6-12.]

Parker, E. *The Universe.* 1983, Cambridge U. Press. Picture book on astronomy for very young children.

Poynter, M. & Klein, M. *Cosmic Quest.* 1984, Atheneum. A nice introduction to the search for life elsewhere in the universe. [Ages 13 and up]

Taylor, G. *Volcanoes in Our Solar System.* 1983, Dodd, Mead. Discussion of volcanoes on Earth and on other planets & moons. [13 and up] ■

Two Summer Workshops of Interest to Teachers

"The Universe in the Classroom" in Boston

The Astronomical Society of the Pacific will hold its first-ever meeting on the East Coast at Boston University from July 13-18, 1990. As part of the program, there will be a two-day workshop on teaching astronomy in grades 3-12, offered on Saturday and Sunday, July 14 and 15. A unit of graduate-level credit will be available from the Boston University School of Education.

The workshop includes:

- hands-on activities for teaching basic astronomical concepts
- discussions of resources for teaching astronomy — including books, articles, science fiction, audio-visual materials, computer software, telescopes, etc.
- nontechnical talks on recent developments in our exploration of the universe (including the Hubble Space Telescope)
- a guide to answering questions from students (and Nancy Reagan, should she somehow get to your classroom) about astrology
- comprehensive handouts
- a Saturday evening star party at the Boston Museum of Science
- an exhibit of educational materials.

To receive a registration brochure for this workshop, write to the A.S.P. or use a photocopy of the coupon below. *Send copy of coupon to:* Workshop Information, A.S.P.
390 Ashton Ave.
San Francisco, CA 94112

Please send me registration information for the teachers' workshop in Boston, July 13-18:

Name:_____

Mailing Address:_____

_____
zip

❑ Please also send information on the rest of the Boston Meeting (which will be more technical)

Hubble Space Telescope Workshop in Baltimore

The Johns Hopkins Space Grant Consortium and the Space Telescope Science Institute Office of Educational and Public Affairs are sponsoring a 3-day workshop for 300 high school teachers interested in astronomy and space science, June 18-21, 1990 in Baltimore. The program will provide up-to-date information about and (we hope) early results from the Hubble Space Telescope and the Hopkins Ultraviolet Telescope projects.

The workshop will be led by Dr. Eric Chaisson, Senior Scientist and Director of Education for the Space Telescope Science Institute, assisted by Dr. Philip Sakimoto, plasma astrophysicist and Assistant Director of the Space Grant Consortium. The program includes lectures, discussions, and sessions on laboratory methods and classroom projects; new resource materials will be distributed.

Room and board will be provided for participants from outside the immediate area. Participants will be chosen on a rolling schedule based on geographical distribution, involvement in space science courses, and order of applications.

For applications, write to: Johns Hopkins Space Grant Consortium, HST-HUT Teachers' Workshop, 135 Rowland Hall, 34th & Charles Streets, Baltimore, MD 21218. *(Note: the coupon above is not for this workshop.)*

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The Latest News on the Hubble Space Telescope: Flawed but Working and Fixable

During the past spring and summer, the eyes of the astronomical community were riveted on the dramatic news of the Hubble Space Telescope (HST). Launched into perfect orbit after long delays, the telescope began its months-long engineering check-out phase with everyone's hopes held high. Then came the shocking revelation: due — it appears — to an error at the company that manufactured its pioneering mirror, the telescope had a major flaw. The flaw sounds minor at first hearing: the mirror is the wrong shape by about 1/50th the width of a human hair. Yet that small aberration is enough to endanger a wide variety of projects planned with the telescope — at least until astronauts can go back in a few years and make repairs. We devote this issue of *The Universe in the Classroom* to HST — its potential, its problems, and its current status.

What kind of telescope is HST and what was it designed to do?

The Hubble Space Telescope is the largest and most complex telescope ever put into orbit. It is a *reflector,* which means it uses a mirror to collect light and bring it to a focus. HST's main mirror is 2.4 meters (94 inches) in diameter and is made of titanium silicate glass, which does not expand or contract very much when it is heated or cooled. (That's important because the telescope orbits the Earth every 96 minutes, and goes through a "day" and a "night" during each orbit.) There are a number of larger reflecting mirrors used for astronomy on Earth — the famous telescope on Mount Palomar in Southern California has a 5-meter (200-inch) mirror and the new Keck Telescope, soon to start operations in Hawaii, will boast a 10-meter mirror when all its segments are in place. But the HST has the distinct advantage of being in space, above the often murky, jittery, and glowing layers of our planet's atmosphere.

HST's mirror is also the smoothest ever made: if the 94-inch mirror were scaled up to be the size of the United States, the surface would have no imperfections greater than 2.5 inches! It took 150 person-years to create a mirror that smooth — which is why astronomers were so concerned that the ultimate curve of the mirror turned out to be wrong.

Since we already have bigger telescopes on the ground, why bother with a 94-inch telescope in space?

Observing the universe from the surface of the Earth is like trying to watch a game of baseball from the bottom of a swimming pool. Even if the players are all in view, from your vantage point under the water the details of the game can be hard to make out.

The many layers and pockets of air above us are in constant motion and the resulting jiggling of the atmosphere not only makes stars twinkle, but also makes the images we see of all celestial objects look fuzzy. Typically, the Earth's atmosphere spreads out star images from a sharp point to a

continued ☞

This image of Saturn was taken with HST's Wide Field/Planetary Camera Aug. 26, 1990, when Saturn was 1.4 billion km (860 million mi) from Earth. It and other HST photos show the ringed planet with almost as much clarity as the Voyager flyby images. (Courtesy NASA/Goddard)

fuzzy patch one *second of arc* in diameter. (A second of arc is roughly the size of a dime as seen from two miles away.) While that sounds pretty small, for frontier astronomical projects, when we are trying to see the inner details of some complex galaxy or just trying to separate two stars that are very close to each other in a crowded cluster, we need to do much better than that. Up in space, above the atmosphere, HST should be able to show images that are *10 times* sharper. Astronomers call the telescope's ability to see detail its *resolution* — and HST's better resolution was a major factor in the decision to build it.

In addition, putting the telescope above the Earth's atmosphere helps to reduce the background glow of light that enters the instrument. Here on Earth, the layers of air above us glow at night, both by scattering the light from the Moon and the stars, and also by producing their own light as charged particles from space hit the atmosphere's upper layers. This "sea of background light" is very faint, but becomes a crucial "barrier" for astronomers trying to observe the even fainter light of distant objects.

With HST, we can literally rise above this problem, some 380 miles above the Earth's surface. Because there is no twinkling of the images, astronomers using HST will also be able to measure the rapid variations of cosmic objects much more precisely than from the ground. And last, but certainly not least, HST will be able to detect forms of light that our atmosphere filters out. Primary among these will be *ultraviolet* light — a little of which gets through to give suntans to those Earthlings not protected by dark skin-coloring — but most of which is absorbed in the ozone layer. Yet many celestial objects, often those which are most violent and energetic, give off ultraviolet light and we are eager to learn more about the cosmos by studying it.

What specific instruments will be used to analyze the light HST's mirror gathers?

Collecting the light and bringing it to a focus is only the first step in doing astronomy. Then the light has to be recorded and analyzed to understand the messages it is bringing us from distant stars and galaxies. HST has six instruments to which its light can be directed: two cameras, two *spectrographs* (instruments for spreading out the light into a spectrum), a high speed *photometer* (a fast, accurate light meter), and "fine guidance sensors" for measuring the positions of stars with unprecedented accuracy.

There are *two* cameras on board HST because each is designed to do different kinds of work. The Wide Field and Planetary Camera (WF/PC) is designed to look at brighter objects and wider fields of view. It has already sent back the spectacular photograph of the planet Saturn seen on page one. The Faint Object Camera (FOC), as its name implies, is designed to see the faintest objects in the universe, but also to show the most detail possible. Both cameras will record the images they form not on film, but on extremely sensitive electronic light detectors called *charge-coupled devices* (CCD's).

In fact, such CCD light detectors are part of a quiet development in technology that is revolutionizing astronomy on the ground as well as in space. A piece of film records only a small fraction of the light that falls on it; in contrast, as much as 70% of the light can be recorded by a CCD. The WF/PC is equipped with a CCD detector that can record the light falling onto 256 million individual picture elements (*pixels*, as scientists call them). This camera will be on whenever the telescope is operating, translating the precise amount of light hitting each pixel into a digital readout that will be sent back to Earth regularly. Over the years, the output of this instrument will form a permanent record of what HST "saw" as its other instruments scan the universe.

The FOC also uses an electronic light detector, but it adds another technological twist to the light. Inside the camera are state-of-the-art *image intensifiers* — essentially light amplifiers that can take the faintest bits of light and make them brighter without changing them. In principle, these devices work the same way as the amplifier in your home stereo system, which takes the weak signal produced by the cartridge in the turntable and makes it strong enough to blast the neighbors with the full impact of Tchaikovsky's *1812 Overture*. Similarly, the modern light amplifiers can take the very weak light signals from remote objects and — without altering the precious information they carry — can amplify them to be as much as 100,000 times brighter than the original light.

What scientific projects is HST going to undertake?

It would take several issues of this newsletter to discuss the many projects astronomers hope to carry out during HST's 15-year lifetime. Proposals have come in to undertake research in almost every branch of astronomy — looking at objects as close as Mars and as far away as the farthest known *quasars*, the most remote objects in the universe, thought to be the energetic centers of newly forming galaxies, seen as they were billions of years ago.

Here are just a few of the projects that will eventually be done with HST, to give you a taste of what's being planned:

- How does the weather on Jupiter change with time and what can the continent-sized storm systems in its fast-moving atmosphere tell us about weather on Earth?
- Are there planets around other stars?

The Universe in the Classroom

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- What sorts of stars explode at the end of their lives, and which stars end their existence in more peaceful ways?
- How soon after the Big Bang did galaxies of stars start to form?
- Are there giant *black holes*, places where gravity has overwhelmed everything, at the centers of *all* galaxies or are they limited to certain types of galaxies?
- How important is *galactic cannibalism* (where a larger galaxy swallows a smaller neighbor) to the evolution of galaxies in clusters?
- How old is the universe and will it expand forever or someday contract?

What exactly happened with HST's mirror?

It appears that when the mirror was being polished to the right shape, the device used to test its curvature — called a *null corrector* — had been made to the wrong specifications. Thus, when the null corrector showed that the HST mirror was as close to perfect as it could be, it was actually ever so slightly the wrong shape.

This kind of error in making mirrors is called *spherical aberration*, and it is so well known that it appears in just about every introductory astronomy textbook. What it means is that the the light being collected from across the mirror does not come to a focus at a single point as it is supposed to. Instead, light rays hitting the edge of the mirror focus to a point about one inch away from the where light rays from the mirror's center focus.

How does the mirror flaw affect the working of the telescope?

To make images significantly sharper than can be done from Earth, HST was supposed to concentrate 70% of the light from a star into a very narrow "core" of light. With the mirror problem, only about 15% of the light is concentrated into this narrow core — the remainder is spread out into a less sharp "halo" of light that is about as large as the best images we can get from the ground (about one second of arc.) In other words, the majority of the image is fuzzy, and only a small fraction of the light is as sharp as HST's designers had hoped.

Now here is the good news: if you are observing a bright object, you can afford to throw away much of the light — and only use the part that is in sharp focus. Modern computer processing techniques can let you do away with the fuzziness and just use the light in the core. But since HST was supposed to look at many objects that are so faint we can barely detect them, there will be many situations where astronomers will need every bit of light they can collect. In that case, the halo cannot be processed out, and — until repairs can be made — we will have to be content with a fuzzy image. (Actually, each of the HST's instruments is affected by the mirror problem in a slightly different way. Experts associated with each instrument, as well as experts in the computer enhancement of astronomical images, studying the workings of each instrument to see w and can't be done.)

In the meantime, engineers report that, ironica electronic systems and all six of the main instrumen the telescope seem to be working as well or better been planned. (There is still a wobble which see caused by the solar panels reacting to changes fr ness to light, but engineers hope to have its effe mized by changes in the commands issued to the te All of this makes the mirror flaw even more frus those astronomers who have spent over a decade d the instruments for NASA and were hoping by no the rich rewards of being given "first dibs" on exciting astronomical problems of our day.

Can the problem be fixed?

Without bringing the whole telescope back nothing can be done at this point to fix the mirror its solutions now being considered involve doing s with the light *after* it has reflected off the main m before it reaches the light detecting devices in ea ment.

Luckily, because the mirror error is so uniform it does not seem to be difficult to put correcting mirrors into the light path or the instruments to damage the mirror flaw has caused. Unfortuna "contact lens" correctors cannot be put on th instruments because the astronauts cannot h mirrors or lenses with their bulky space-suit gloves before the flaw was discovered, NASA had alre plans to bring up a new improved Wide Field and Camera and insert it into the telescope in 199 instruments were designed to be modular for eas and replacement in case they suffered problems mers at Caltech and the Jet Propulsion Lab working on the new generation camera repor should have no problem in designing the new s just the right error to cancel out the problem the m is causing.

Other instruments, now planned for a 19 mission, can also be designed to compensate fo problem and thus deliver sharp images once aga issue was going to press, engineers were also l more dramatic plan to replace one of the instrum "black box" with a sort of "robot arm" that wo correcting optics into the light beam reaching *all* instruments.

What can be done in the meantime?

Some of the projects planned for the first f HST operations, especially those dependent on greatest detail in very faint objects or in crowd view, will have to be postponed until repairs ca But many other projects can go ahead as planne if each observation is given more time on the te that more light can be gathered. Teams of astro

going over the details of the observing schedule to make best use of the telescope's current abilities. Certainly, everyone involved with HST hastens to point out that media stories discussing the complete failure of the telescope were grossly exaggerated. HST may be flawed but it is not broken!

While the scientific work of the telescope is just beginning, the cameras have already sent back some spectacular photographs, including the best image yet of the distant planet Pluto and its mysterious moon Charon and a pioneering view of the center of a complex cluster of stars at the heart of the Tarantula Nebula. We will keep our readers informed about the progress of HST in future issues of the *Universe in the Classroom.* ■

For Further Information:

Field, G. & Goldsmith, D. *The Space Telescope: Eyes Above the Atmosphere.* 1990, Contemporary Books. The best introductory book about HST. (A section was adapted into an article in *Mercury* magazine, Mar/Apr. 1990, p. 34.)

Smith, R. *The Space Telescope.* 1989, Cambridge U. Press. A scholarly history of the HST project.

The April 1990 issue of *Sky & Telescope* magazine was devoted to HST and has several good articles about all aspects of the project.

Maran, S. "The Promise of the Hubble Space Telescope" in *Astronomy*, Jan 1990, p. 38.

Villard, R. "The Space Telescope at Work" in *Astronomy*, June 1989, p. 38.

Articles on the Mirror Problem and Solutions:

Begley, S., et al. "Heaven Can Wait" a cover story in *Newsweek*, July 9, 1990, p. 48.

Fienberg, R. "Space Telescope: Picking Up the Pieces" in *Sky & Telescope*, Oct. 1990, p. 352.

Villard, R. "The Hubble Space Telescope: Problems and Solutions" in *Mercury*, Sep/Oct. 1990, p. 141.

Waldrop, M. "Astronomers Survey Hubble Damage" in *Science*, July 13, 1990, p. 112; "The Case of Single Point Failure" in *Science*, Aug 17, 1990, p. 735.

How To Get Slides of the Images from HST

A slide and information kit with 25 images taken of and with the Hubble Space Telescope is now available from the nonprofit Astronomical Society of the Pacific. Assembled with the assistance of the Education Staff at the Space Telescope Science Institute (and a number of other NASA centers and aerospace companies), the set includes:

- paintings and diagrams showing HST operations, instruments, and repair
- photos of HST's deployment taken by the astronauts
- the first set of HST camera images, including Saturn, Pluto, the Einstein Cross, the center of the Tarantula Nebula, the ring around Supernova 1987A, etc.

The slides are accompanied by an extensive booklet with nontechnical background information, detailed captions, and a thorough HST reading list.

To order, send $ 29.95, which includes postage and handling charges, to:

Astronomical Society of the Pacific
HST Slide Set Orders Dept.
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San Francisco, CA 94112

California residents please include sales tax.

Outside the U.S., please add $3.00 for postage and remit in U.S. funds.

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